SCIENCE AND TECHNOLOGY TEXT MINING: DISRUPTIVE TECHNOLOGY ROADMAPS

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14. ABSTRACT
Disruptive technologies create growth in the industries they penetrate or create entirely new industries through the introduction of products and services that are dramatically cheaper, better, and more convenient. These disruptive technologies often disrupt workforce participation by allowing technologically unsophisticated individuals to enter and become competitive in the industrial workforce. Disruptive technologies offer a revolutionary change in the conduct of processes or operations. Disruptive technologies can evolve from the confluence of seemingly diverse technologies or can be a result of an entirely new technological investigation. Existing planning processes are notoriously poor in identifying the mix of sometimes highly disparate technologies required to address the multiple performance objectives of a particular niche in the market. For a number of reasons, especially the inability to look beyond short-term profitability, and the risk/ return tradeoff of longer-term projects, it is suggested that current strategic planning and management processes promote sustaining technologies at the expense of disruptive technologies. We propose a systematic approach to identify disruptive technologies that is realistic and operable and takes advantage of the text mining literature. This literature-based discovery process is especially useful in identifying potential disruptive technologies that may require the input from many diverse technological and management areas. We believe that this process holds great potential for identifying projects with a higher probability of downstream success. Further, we suggest a process to take the identified potential disruptive technology from the ?idea stage? through the development of a potentially feasible product for the market. This second stage makes use of workshops and road-mapping to codify the ideas of technological and management experts, who were identified in the literature-based discovery stage. Our goal is to describe and explain the pragmatic steps suggested by our innovative and practical process. The proposed process could identify technologies whose eventual development and application to specific problems would identify innovative products. The goal is to isolate technologies that have the potential to redefine an industry , or alternatively, have the potential to create an entirely new industrial setting. We use the text mining component of literature-based discovery to identify both the technical disciplines that are likely candidates for disruptive technological products, and experts in these critical technical and managerial disciplines. While we know that this is but one way to investigate nascent disruptive technologies we feel that it is imperative that the representatives of these potentially critical technical disciplines are included in the roadmap development process, either as implementers or as consultants. Every firm is looking for the ?next great thing?. Literature-based discovery offers a starting point for identifying at least a portion of the major contributory technical and managerial disciplines necessary for potential disruptive technologies and discontinuous innovations. Combining literature-based discovery with a practical workshop/ roadmap process dramatically

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Abstract

Disruptive technologies create growth in the industries they penetrate or create entirely new industries through the introduction of products and services that are dramatically cheaper, better, and more convenient. These disruptive technologies often disrupt workforce participation by allowing technologically unsophisticated individuals to enter and become competitive in the industrial workforce. Disruptive technologies offer a revolutionary change in the conduct of processes or operations.

Disruptive technologies can evolve from the confluence of seemingly diverse technologies or can be a result of an entirely new technological investigation. Existing planning processes are notoriously poor in identifying the mix of sometimes highly disparate technologies required to address the multiple performance objectives of a particular niche in the market. For a number of reasons, especially the inability to look beyond short-term profitability, and the risk/return tradeoff of longer term projects, it is suggested that current strategic planning and management processes promote sustaining technologies at the expense of disruptive technologies.

We propose a systematic approach to identify disruptive technologies that is realistic and operable and takes advantage of the text mining literature. This literature-based discovery process is especially useful in identifying potential disruptive technologies that may require the input from many diverse technological and management areas. We believe that this process holds great potential for identifying projects with a higher probability of downstream success. Further, we suggest a process to take the identified potential disruptive technology from the "idea stage" through to the development of a potentially feasible product for the market. This second stage makes use of workshops and roadmapping to codify the ideas of technological and management experts, who were identified in the literature-based discovery stage. Our goal is to describe and explain the pragmatic steps suggested by our innovative and practical process.

The proposed process could identify technologies whose eventual development and application to specific problems would generate innovative products. The goal is to isolate technologies that have the potential to redefine an industry, or alternatively, have the potential to create an entirely new industrial setting. Use the text-mining component of literature-based discovery to identify both the technical disciplines that are likely candidates for disruptive technological products, and experts in these critical technical and managerial disciplines. While we know that this is but one way to investigate nascent disruptive technologies we feel it is imperative that the representatives of these potentially critical technical disciplines are included in the roadmap development process, either as implementers or as consultants.

Every firm is looking for "the next great thing". Literature-based discovery offers a starting point for identifying at least a portion of the major contributory technical and managerial disciplines necessary for potential disruptive technologies and discontinuous innovations. Combining literature-based discovery with a practical workshop/roadmap process dramatically enhances the likelihood of success.

This report ends with a partially annotated bibliography on disruptive technologies.

1. Introduction

Disruptive technologies can be either a new combination of existing technologies or new technologies whose application to problem areas or new commercialization challenges (e.g., systems or operations) can cause major technology product paradigm shifts or create entirely new ones [1]. Management researchers have studied the commercial potential for disruptive technologies for nearly a century. Kondratief [2] and Schumpeter [3] were among the early researchers in the field suggesting "Long waves of technological change and the process of creative destruction caused by new technologies and new skill sets either creating or redefining firms and existing markets".

The recent interest in the field has ignited numerous differing arguments for the exact definitions of either disruptive technologies or discontinuous innovations. *Disruptive technologies* can be considered scientific discoveries that break through the usual product/ technology capabilities and provide a basis for a new competitive paradigm. *Discontinuous innovations* can be considered products/processes/services that provide exponential improvements in the value received by the customer. Disruptive technologies have been referred to as earthquake, game breaking, whirlwind, typhoon, or emergent technologies. The nomenclature is not important but the phenomena are. Disruptive technologies are by their nature nascent and only can be revealed as being disruptive in hindsight. They therefore provide a major problem for a technological forecaster or roadmapper, requiring a degree of insight not

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required for sustaining technologies (albeit high tech) that follow the established technology product paradigm in a given industry [4]. Products based on disruptive technologies provide dramatic improvements to current product market paradigms, or produce the physical and service products that initiate new industries. These regime changes define a new product platform, which is far different from what the market would have experienced with "only" incremental innovation.

One challenge in the study of discontinuous and disruptive innovation is the lack of widely accepted definitions. Definitions of disruptive technologies focus on firm-based product technology factors [5]; industry wide product technology factors [6]; and the gap between substitutable technological learning curves on cost or performance basis [7,8]. Definitions of discontinuous innovation focus on customer behavior [9], product newness [10], market factors [11] or some combination of these factors [12].

Disruptive technologies create major new growth in the industries they penetrate by allowing people and firms with differing skill sets to provide step function value to existing industries or create new ones from the value they provide. An examination of the successful disruptive technologies suggests that they provide exceptional value to less satisfied customers of the current technology product paradigm [9]. In the past few decades, consumers have accepted products and services that have been enabled by disruptive technologies. Many of these have been (1) smaller, (2) lighter, (3) cheaper (4) more flexible and convenient, (5) more reliable, (6) more efficient with higher unit performance (energy density, computing power, etc.), and (7) operationally simple. Disruptive technologies offer a revolutionary change in the conduct of processes or operations.

To meet multiple consumer-based performance objectives, disruptive technologies typically draw upon many diverse technologies. For example: (1) Smaller products may require advances in micro- or nanotechnologies; (2) Lighter products may require advances in materials technologies; (3) Cheaper products may require advances in component technologies and associated manufacturing processes; (4) More flexible and convenient products may require advances in human factors research, ergonomics, and artificial intelligence; (5) More reliable products may require advances in design, manufacturing and quality control processes, and probability and statistics; (6) Higher unit performance products may require advances in chemistry and physics, materials, heat transfer, design, and micro- and nanotechnology manufacturing processes; (7) Operationally simple products may require advances in artificial intelligence, robotics, and design. Existing planning processes are notoriously deficient in identifying the mix of highly disparate technologies required to address the multiple performance objectives necessary to suggest potential disruptive technologies. In fact, it is paradoxical that "disruptive planning processes" are required to replace today's "sustaining planning processes", in order to systematically identify potentially disruptive technologies and their associated development strategies.

The common usage of disruptive technologies in the literature focuses on new, typically revolutionary, technologies. While the underlying concept of revolutionary technologies is not new [13], the potentially devastating impact of these technologies on successful industries has received attention in books and articles by Christensen et al. [14], Christensen [15], and Moore [9], and more traditional pieces by Schumpeter [3]. Further entrepreneurial authors such as

Kirchhoff and Walsh [16] and many of the disruptive technology researchers cite that why successful and apparently well-managed organizations fail is that they do not recognize the distinction between sustaining technologies and disruptive technologies. Entrepreneurial firms with no established customer base can take advantage of disruptive technologies and redefine current markets whereas large firms refuse to cannibalize their own markets through the use of disruptive technologies.

Sustaining technologies are those that improve the performance of established products through the current technology product paradigm. They are often developed by successful companies for, and in close collaboration with, their most important and lucrative clients [16]. In other words, they are often the result of those successful firms following the excellent business practice of *listening closely to their customers* (see Ref. [17], also Ref. [16]).

In contrast to sustaining technologies, which improve the performance of established products, disruptive technologies often provide value parameters not recognized by the mainstream market and might actually provide worse product performance features on some parameters valued by the mainstream market, at least in the short run [17].

Successful companies often fail to invest aggressively in nascent disruptive technologies, to their long-term demise and dismay. Possible reasons for their demise include: first, disruptive products are simpler and cheaper; they generally promise lower, not higher, profit margins; second, disruptive technologies typically are first commercialized in emerging or insignificant markets; and third, leading firms' most profitable customers generally do not want, and indeed initially cannot use, products based on disruptive technologies [18]. By and large, the product embodiment of a disruptive technology is initially embraced by a small fraction of customers in a market. Hence, most companies with a practiced discipline of listening to their best customers and identifying new products that promise greater profitability and growth are rarely able to build a case for investing in disruptive technologies until it is too late [14,17].

Kirchhoff, Christensen, Moore, and others make a rather convincing case that the very rational refusal by successful companies to invest in disruptive hard or soft technologies can lead to their rather sudden loss of dominance in their respective fields, if not their total disappearance. It is certainly possible to extrapolate this disruptive technology scenario to national defense, with the potential consequence of shifting national military dominance.

There are at least two main generic reasons why sustaining technologies tend to be preferred at the expense of disrupting technologies in large firms: incentives and procedures. The larger firms are driven by quarterly profitability. A technology with the potential to radically reduce the cost of a product, but whose application is years in the future, and whose cost is being borne currently, is likely to reduce current profitability, and unlikely to enhance one's upper management career. The incentive problem in both the commercial and national defense sectors is that the larger social benefits require a longer term global optimization objective function (i.e., the common good), whereas individual incentives are driven by shorter term local optimization objective functions (i.e., the individual good). In plain English, the near-term individual rewards from sustaining technologies that yield short-term low-risk payoffs displace the longer term social benefits that could result from proactive high-risk high-payoff disruptive technology selection. The procedural problem is that technology selection decisions, especially in large established commercial and government organizations, are increasingly being made by larger and more inclusive committees, a process traditionally steeped in tradition and conservatism. Revolutionary disruptive concepts are less likely (on average) to receive committee approval than evolutionary sustaining concepts.

To guard against the potentially devastating consequences caused by the introduction of disruptive technologies, whether in the commercial or national defense sector, a number of strategic steps are required. The main step required is a change in the strategic orientation at most firms. A longer range strategic perspective that is better able to evaluate and anticipate short- and long-run risks is needed to restore balance to the typically shorter range tactical reactive operational mode. The incentives necessary to affect this paradigm shift are beyond the scope of this paper. Our hope is that practical research approaches like the one advanced in this paper will facilitate the necessary change in corporate culture. Once this managerial and cultural hurdle has been overcome, then, processes can be developed to identify, plan for, and develop technologies with higher probability of having disruptive impact.

In this paper, we present processes that will facilitate the generation of potentially disruptive technologies. The key features of these processes are: (1) they insure that a wide range of alternative candidate technologies are considered for disruptive scenarios; (2) they identify many of the technical and managerial disciplines required to develop the highest priority alternative candidate technologies, and incorporate them in the development plan for the alternative technologies selected; (3) they use tandem literature-, workshop-, and roadmap-based approaches to exploit the strengths of each and eliminate the weaknesses of each. In the remainder of this paper, a literature/workshop/roadmap-based approach to systematically identify, plan for, and develop potentially disruptive technologies is advanced.

2. Objectives

This paper aims to develop a process that will facilitate the identification of potentially disruptive technologies, and to provide a systematic approach for developing and implementing such technologies.

3. Approach

3.1. General

There are two broad perspectives in the generation of a nascent disruptive technology. The first is a market-based approach where firms perceive a need in the market and then generate the technologies necessary to meet the need. This top-down mode starts from a modified operational scenario, and then generates the requirements for a technology that will result in disrupted operations. Another possible starting point is to evaluate the firm's technological strengths and then look for a market niche to apply the core capabilities of the firm. This bottom-up mode, starts from technologies already being developed, or being considered for development, and then identifies the operational scenarios and markets that these technologies could disrupt. The firm must find a new way of addressing an existing or potential opportunity that will disrupt the then current managerial and technological orientation. This paper addresses a firm's proactive search for a disruptive technology. Since it is often the case that an industry is redefined by technologies initially exogenous to the industry [16], text mining is essential to this endeavor.

A firm's proactive search, in either case, suggests that candidate technologies must be evaluated and prioritized. For example, assume the commuting gridlock in major metropolitan areas is the problem to be addressed. In the top-down mode, disruptive concepts for commuting (or eliminating commuting) need to be envisioned. Suppose that individual jetpacks, such as those used in some of the old James Bond movies, were being considered as a candidate for solution. Adoption of such a commuting concept on a large scale would certainly disrupt the status quo. In the bottom-up mode, a researcher pursuing the study of magnetic levitation could show potential disruption of the commuting market by magnetically moving elevated containers of people around the metropolitan area.

Second, a process must be generated to plan for, and develop, one or more candidate disruptive technologies systematically. These candidate disruptive technologies would have to meet the characteristics needed by the market as identified in the introduction, characteristics that the old James Bond jetpack certainly did not have! In the general case, these technologies will require discovery and innovation, and may require both multi- and interdisciplinary input. Thus, this second step would probably require the systematic development of innovative multidisciplinary technologies.

The approach used in the present paper for both steps is generically the same. It differs in specifics, because the level of problem definition in the two steps differs. In both steps, a literature encompassing the problem to be solved is generated, the technology components of the literature are identified, experts in each of the component technical disciplines are identified, and then convened in a group format to elucidate the steps necessary to solve the problem. The first step, identifying the potential disruptive technologies, would utilize a workshop approach involving managerial and technological experts, who had been identified in the initial literature-based phase. The second step, the identification of the development strategy for each of the candidate disruptive technology alternatives selected, would utilize a roadmapping approach of managerial and technological experts, who had been identified in the initial literature-based phase and had further developed their ideas in the workshop-based phase.

3.2. Specific

3.2.1. Identifying candidate technology alternatives

The first step is to define the problem or opportunity to be addressed. This obviously takes great skill and intuition and would need to be supported at top managerial levels. Once the problem has been defined, then the literature base that will be used to identify technology alternatives and associated experts needs to be defined. The next step is to use the most advanced information technology methods to retrieve the full literature that addresses the problem [19,20].

For example, in the metropolitan area gridlock problem, the traffic congestion literature would be retrieved. Different types of congestion should be included, not only automobile traffic. These alternatives might include air, sea, and land traffic, bird, fish, insect, and land animal traffic, and maybe communications traffic as well. Congestion is a problem in most types of traffic, and the thinking that has been done in one of these areas may have insights to offer other conceptually similar areas. For example, a recent citation mining study on vibrating granular systems (sandpiles) research showed that physical concepts and principles arising from granular flows and associated particle interactions were being extrapolated to studies on air and ground traffic congestion [21].

This literature would be combined, and placed in a structured format if appropriate or kept fully unstructured. Then, clustering techniques would be applied to the literature that will result in identifying the main technology categories [22–24]. Various alternative concepts would result from the clustering, and key people (and organizations) associated with those alternative concepts would be identified. Experts representing all the alternatives would be invited to a workshop, and the most promising solution alternative(s) would be identified by various "brainstorming" techniques (see Refs. [25–27] for successful examples of such workshops).

It is envisioned that two major types of potential solutions would be identified. One would be technology based, the other not technology based. For example, in the traffic congestion problem, the individual jetpack could represent a technology-based solution, and could be a disruptive technology in Moore's [9] or Veryzer's [28] market penetration sense. Mandating different business starting times would represent a non-technology-based solution, and would be disruptive in the sense of changing the status quo to alleviate the problem. Further, of the technology-based solutions, some could be existing technologies, or modest extensions of existing technologies, whereas others would be revolutionary technologies. For those technologies already being researched, or considered for research, this step would represent a merging of the top-down bottom-up technology identification processes. The revolutionary technologies to be developed are the focus of this paper, although any of the other categories mentioned could be equally important, or more so, for the actual implementation.

3.2.2. Identifying technology components

Once the high priority technology alternative(s) have been identified and prioritized, then a strategy and plan must be generated for developing and demonstrating this technology(s). The present approach is based on: (1) using literature-based discovery to identify the critical technology components of each technology alternative; (2) identifying experts for each of these identified technology components; (3) convening these experts in a workshop to identify the component technology characteristics further; and (4) having these experts collaborate collectively to generate a roadmap for developing and demonstrating each technology alternative.

3.2.2.1. Literature-based discovery to identify critical technology components

Overview. Text mining is the extraction of useful information from text, typically large volumes of text [29–32]. One of the major components of text mining is literature-based discovery [26,27,33–38]. Literature-based discovery identifies the major technical disciplines that are required to comprehensively address a technology problem, and has the potential to generate innovation from expert analysis of published documents. The application of text mining to the identification of potential disruptive technologies for a given technology product paradigm problem requires great insight by the user. The initiation of formalization of a process to utilize text mining is necessary to decrease the time required for disruptive technologies to be utilized in the commercial and governmental sectors.

The starting point for literature-based discovery is to identify multiple literatures that are both complementary and disjointed. Complementary means that each literature contributes part of the solution to the innovation and none of the component literatures can stand on its own in generating the complete innovation. Disjointed means that the literatures are independent. The synergy from integrating multiple, seemingly unrelated literatures, is the magic that gives this process such potential.

The basic assumption in the literature-based discovery concepts that have been published is that innovative solutions to problems can be obtained through literature paths that indirectly relate the problem to the solution. Thus, if problem A is expressed through literature AB, where B is some intermediate theme, then solution C may be expressed through literature BC. B is the intermediate theme connecting solution C to problem A.

For example, in the first reported study of literature-based discovery [33], a treatment for the circulatory disease Raynaud's Syndrome (problem A) was the desired target. A search was made for all articles pertaining to Raynaud's Syndrome (literature AB). Swanson identified blood viscosity (intermediate theme B) as a strongly linked theme to Raynaud's Syndrome, and then retrieved the blood viscosity literature (literature BC). Based on analysis of literature BC, Swanson eventually identified fish oil/eicosapentaenoic acid (solution C) as a potential treatment for Raynaud's Syndrome (problem A) due to its impact on blood viscosity (and other blood rheology properties). This was later validated through clinical trials.

Coincidentally, if Swanson's finding could be shown to have a major impact on the treatment of Raynaud's Syndrome, it could be viewed as one type of candidate disruptive technology, albeit not in the revolutionary technology category. A low cost low technology readily available product such as fish oil could potentially displace high cost high technology corporately protected drugs from the market. In this example, the virtual disruptive technology did not require multiple technical disciplines for its production, but rather for its identification.

In general, after a full literature for each topic of interest has been generated, the method of solution proceeds according to the type of question asked. If, following Swanson's medical examples [33,34], one literature represents a disease, and the other literature represents a treatment, then the question might revolve around determining the mechanism that allows the treatment to work. Or, if the starting literature represents a potential treatment, then the question might revolve around diseases that could be impacted by the treatment (see Kostoff [26] for a more complete listing of the possible permutations).

The next step in the analysis is to generate phrases/concepts from each literature, and then examine the phrases/concepts that are shared by both literatures (or more in the case of multiple literatures). The mainstream approaches today use Title Words or Keywords as the databases for generating phrases, although a recent provisional patent application uses Abstracts (readily available), and when full text becomes available, could just as easily use full text [29]. The mainstream approaches today use various statistical approaches to cull the list of overlapping phrases to be examined. The method proposed in Kostoff [29] uses clustering, in addition to the above filters, to identify phrases/concepts that link the multiple literatures.

Specific. As described above, literature-based discovery involves identifying a literature AB that represents the problem to be solved (where A is the specific problem to be solved and B is a related technology within the literature), then identifying a literature $B'C$ that represents a potential solution to the problem (where B' is the full literature of the technology B identified in AB and C is the potential solution to the problem A not contained in literature A), and using some computational/logical approach to identify the highest probability solution(s) C. This concept is the basis for discovery, and the two-link implementation is the most elemental form.

In practice, there can be many related literatures and many different solutions (or solution components) $B1'C1$, $B1'C2$, $B2'C1$, $B2'C2$, and so on. In addition, there can be more than one step (i.e., more than two links) connecting the problem to the solution(s) (e.g., $AB \rightarrow B'X \rightarrow X'C$, where both B and X are intermediate linkages). The final schematic must be sufficiently general to incorporate each of the elemental linkages above into the final multistep multiintermediate literature multisolution schematic.

The first step in identifying the technology component disciplines is to retrieve the technology literature of interest. For example, following the medical treatment approaches Swanson has taken, if the problem is to identify treatments C for a disease A, the existing literature for that disease would be retrieved from the appropriate database(s). Once this literature AB is obtained, it is then processed through computational linguistics to identify its main characteristics B1, B2, B3, ..., or themes related to the central problem. A query is developed for each of these themes, and a literature is retrieved for each of these themes ($B1'$, $B2'$, $B3'$, ...). Computational linguistics is applied to each of these related literatures to identify both the main themes of each of these literatures and subthemes within the main themes. Main themes/subthemes that are common across the literatures related to the problem of interest and/or subthemes that have high occurrence frequencies are examined, and those that have a rational relationship to the central problem are selected as high probability of innovation technologies.

Fig. 1 is a schematic representation of this literature linkage process. Each column represents a literature–theme combination. Fig. 1A is the most elemental case, a two link schematic with one intermediate theme B and one solution C. Thus, AB in column 2 is translated as the literature for problem A with intermediate theme B. Further, BC in column 3 is translated as the literature for intermediate theme B with solution C.

While the schematic representation for this linkage process is very simple, the specific technique used to identify theme B and solution C is not. For the initial problem literature AB, there are hundreds or thousands of candidates for theme B. How would the most promising B be selected?

The approach proposed here is from the TexTosterone text mining system (see Ref. [29]). The specific algorithm recommended is summarized in Appendix A. Clustering and factor analysis are two of the statistical clustering techniques performed on the initial literature AB. They are supplemented by nonstatistical clustering approaches that use visual inspection of the elemental phrases in literature AB. These combined clustering analyses will generate the

PROBLEM-->SOLUTION SCHEMATIC

	PROBLEM/ THEME	THEME/ SOLUTION THEME	THEME/ SOLUTION
A ONE INTERMEDIATE B ONE SOLUTION TWO LINKS	AB	BC	
B ONE INTERMEDIATE B ONE INTERMEDIATE X ONE SOLUTION THREE LINKS	AB	BX	XC
C GENERAL CASE	AB	B1C1	
		B1C2	
		B1X1	X1C1
			X1C4
		B1X2	X2C1
			X2C5
		B2C1	
		B2C3	
		B2X1	X1C1
			X1C4
		B2X3	X3C1
			X3C6

Fig. 1. Problem–solution schematic.

main characteristics of problem A. In the present one-theme example, the major characteristic identified by these clustering analyses will be selected as theme B, and then a literature BC will be generated that represents theme B. Within this literature, there will be hundreds or thousands of candidate solutions C. How would the most promising C be selected?

A numerical filtering process is used to eliminate solutions C that are only weakly linked to theme B. Phrase frequency and proximity analyses from the TexTosterone system are applied to BC to identify candidate solutions C that are closely related to the theme B.

Fig. 1B introduces the additional complexity of an extra link (theme) X between the problem A and the solution C. In this case, the solution C is not contained in the literature for theme B, but rather in the literature for theme X, a theme obtained from the literature for theme B. To obtain X, computational linguistics are applied to the theme B literature. Again, the statistical and nonstatistical clustering analyses are applied to the literature for theme B to obtain the main characteristics of this literature. In Fig. 1B, the main characteristic was selected as theme X.

Fig. 1C shows the more general case. The schematic can have a mixture of multiple-link pathways and only two- and three-link pathways are displayed in the present schematic. There are multiple intermediate links B, intermediate links X, and solutions C. In general, the more pathways that terminate in a given (candidate) solution C, the higher the probability that C is a promising solution. Also, the higher the sum of the frequencies of occurrence of a candidate solution C along all the pathways, the higher the probability that C is a promising solution.

The Bs and Cs identified by this process represent the technologies from various disciplines (some potentially very disparate) that could contribute to the solution of problem A. Those disciplines that receive high priorities as a result of the application of the figures-of-merit described above (e.g., number of pathways, frequency sums) should be represented at the subsequent workshop and in the roadmap development.

3.2.2.2. Identifying experts. Experts, from each of the directly related literature themes B identified above, from some of the indirectly related literature themes X identified above, and from some of the candidate solution disciplines C identified above, will be asked to participate in the workshop and ensuing roadmap development. Aggregating the experts (from the disciplines identified in the literature-based discovery process) at the workshops and in the roadmap development increases the chances for innovation, even if the innovation was not clear from the literature-based component alone. This step is of prime importance for those technologies that are inherently multidisciplinary.

3.2.2.3. Convene experts in workshops. Representatives from the major disciplines identified will then be convened in a workshop. If the type of innovation workshop suggested by Kostoff [26,27] is followed, where a premeeting exchange of multiple discipline concepts across the Internet is expert facilitated, a meeting environment for accelerating innovation will have been established. The output from the workshop would be some idea of the specific advances in multiple disciplines required to solve the central technology problem, with the potential for generating specific hypotheses to be tested.

3.2.2.4. Construct roadmap. Once the experts have been selected and the workshop convened and finalized, roadmap construction can be initiated. One general structure for such a roadmap is shown in Zurcher and Kostoff [39]. A four-level roadmap is presented, consisting of research, development, capability, and requirement. Nodes are presented at each level, and links among the nodes are depicted. The nodes in the research and development levels represent existing or proposed research programs and development programs, respectively. The capability level nodes represent target capabilities for which there is a consensus that successful program development could result. The requirement level nodes represent existing or potential top-level needs set by the organization's top management.

Different node and link attributes were delineated by various graphical constructs (colors, shading, etc.). Some of these attributes included cost, funding adequacy, estimate of impact, estimate of funding adequacy, risk, and internal/external program sponsorship. In developing the roadmap for the present study, the research and development levels would be populated by programs focused on the unique advances identified in the B/X (intermediate technologies/mechanisms), and C (technology solution) literatures (expanded by the workshop discussions) described above. The capability and requirement node specifications would have the contents of the A (problem specification) literatures (again expanded by the workshop discussions). The roadmap would effectively use the generic structure of the schematic above as its conceptual starting point, and the roadmap development effort would focus on providing detail and insuring connectivity among the various nodes. Some desirable characteristics of such roadmaps are contained in Appendix B, and additional characteristics are contained in Zurcher and Kostoff [39] and Kostoff and Schaller [40].

Two points deserve emphasis here. As stated in Zurcher and Kostoff [39], key aspects of credible roadmap construction are: (1) insuring that the mix of expertise used for the roadmap is matched to the mix of disciplines required to successfully address the target capabilities, and (2) insuring that relevant research and development being performed in all sectors of the global technical community are represented in the roadmap. Neglect of either of these major aspects will reduce the quality of the roadmap, and may lead to misleading conclusions. The literature-workshop-based precursor approaches used in the present roadmap construction approach will help insure that relevant global R&D will be identified, and the diverse disciplines required to successfully develop the potentially disruptive technologies will be incorporated. Thus, the literature analysis step should be viewed as an important value-added method to assemble the appropriate mix of disciplines for solving the problem of interest. The roadmap development can proceed along the lines of standard roadmapping processes, with the added benefit of having the "right" disciplines available to attack the problem. Undoubtedly, when experts from the promising disparate disciplines are assembled, there would probably be other options inserted in the roadmap that did not come from the literature analysis alone, or even from the workshop.

4. Conclusions

This paper has served to provide means to identify a full range of candidate disruptive technology alternatives, as well as to identify the appropriate subtechnologies necessary for successful development of each candidate technology alternative, using systematic methods that survey all related technological and managerial information that are required. Literature-based discovery offers a starting point for identifying the major contributory technical and managerial disciplines. Coupling literature-based discovery with a subsequent workshop/roadmap development process causes the strengths of literature/workshop/roadmap techniques to be amplified. This process provides a new and valuable approach for identifying potential disruptive technologies and products.

Appendix A. Literature-based discovery algorithm

A.1. Generate initial topical literature

Identify problem to be solved (e.g., treatment for Raynaud's disease).
Select source database (e.g., Medline).

Retrieve all records from source database relevant to problem, using information retrieval approach in Refs. [19–21,42], or any other information retrieval approach.

A.2. Generate initial literature themes

Perform pattern analysis of records, including phrase patterns from free text fields and patterns from other fields if applicable (e.g., authors, journals, institutions, cited authors, cited journals, cited papers, citing authors, citing journals, citing papers). The following algorithm focuses on text fields, but is applicable to all other fields described above.

Extract all phrases from all records, using phrase frequency analysis [24].

Filter all extracted phrases to generate list of high technical content phrases (e.g., eosinophilia, inflammation, anti-RNA, anti-DNA, blood viscosity, platelet aggregation, vaso-spasm, vasoconstriction).

Group high technical content phrases into thematic categories (e.g., inflammation, auto-antibodies, blood rheology, vascular reactivity) using statistical and nonstatistical clustering approaches [24,41].

Generate subcategories for each thematic category (e.g., blood rheology → blood viscosity, platelet aggregation, platelet activation) using statistical and nonstatistical clustering approaches, such that a topical literature can be defined for each subcategory.

A.3. Generate directly related literatures

Generate topical literature representing each thematic subcategory, such that each topical literature is disjointed (non-overlapping) with the original problem literature, as well as disjointed with every other thematic subcategory topical literature (e.g., [blood viscosity NOT Raynaud's] NOT platelet aggregation). Use information retrieval approach of Refs. [19–21,42], or any other information retrieval approach, to generate these topical literatures. These literatures are called directly related disjointed topical literatures.

A.4. Generate directly related literature themes

Extract all phrases from each directly related disjointed topical literature, using phrase frequency analysis [24]. Use filter to select high technical content phrases from each directly related disjointed topical literature (e.g., for blood viscosity: shear, stress tensor, EPA, fish oil, etc.).

Group high technical content phrases into thematic categories for each directly related disjointed topical literature (e.g., for blood viscosity: shear stress, fish, flow resistance) using statistical and nonstatistical clustering techniques [24,41].

A.5. Generate indirectly related literatures

For thematic categories in directly related literatures that are not potential specific solutions to problem, generate disjointed literature representing each thematic category, using information retrieval approach of Refs. [19–21,42], or any other information retrieval approach. These new literatures are called indirectly related disjointed literatures (e.g., for blood viscosity: shear stress, flow resistance).

A.6. Generate indirectly related literature themes

Extract all phrases from each indirectly related literature using phrase frequency analysis [24].

Use filter to select high technical content phrases from each indirectly related literature (e.g., for shear stress: stress tensor, tangential stress, normal velocity).

Group high technical content phrases into thematic categories for each indirectly related literature (e.g., for shear stress: platelet deformability, normal stress, tangential stress) using statistical and nonstatistical phrase clustering analysis.

A.7. Compare candidate solutions in phrase form

For thematic categories from directly related literatures that are potential specific solutions to problem, or for thematic categories from indirectly related literatures that are potential specific solutions to problem, generate list of phrases (using phrase frequency analysis) and phrase combinations/cooccurrences (using phrase clustering analysis) for each thematic category.

Filter lists to select phrases and phrase combinations/cooccurrences that do not occur in problem topical literature (e.g., eliminate all phrases/phrase combinations from these generated lists that appear in the initial Raynaud's literature).

Rank candidacy of phrases and phrase combinations/cooccurrences for potential discovery by number of categories in which they appear, and by the sum of frequencies over all thematic categories.

A.8. Compare candidate solutions in thematic form

For thematic subcategories from directly related literatures that are potential specific solutions to problem, or for thematic subcategories from indirectly related literatures that are potential specific solutions to problem, rank candidacy of subcategories for potential discovery by number of categories in which they appear.

Appendix B. Desirable roadmap characteristics

Science and technology (S&T) roadmaps provide a consensus view or vision of the future S&T landscape available to decision makers [39,40]. Roadmaps can have many geometric structures, including networks and directed graphs. In addition, they provide a systematic approach to defining the pathways from S&T development to achieving the capabilities associated with the long-term vision. More specific requirements, or underlying principles, necessary for a high-quality roadmap can be formulated. These include the following.

B.1. Senior management commitment

The most important factor is the commitment of the roadmap-developing organization's senior management with decision authority to high-quality roadmaps, and the associated emplacement of rewards and incentives to encourage such roadmaps. This includes a commitment to a strategic long-term roadmapping process, not just an independent one-time exercise.

B.2. Role of roadmap manager

The next important factor is the roadmap development manager's motivation to construct a technically credible and visionary roadmap. The roadmap manager sets the boundary conditions and constraints on the roadmap scope, structures the working groups, and selects the final roadmap elements from myriad inputs. In some organizations, the roadmap manager has the latitude to establish the complete roadmap development process and criteria, and decide on the make-up of roadmap participants with the requisite expertise.

B.3. Competence of roadmap participants/team

The development experts' competence and objectivity are extremely important. Each expert should be technically competent in his/her subject area, and the competence of the total roadmap development team should cover the multiple research, technology, and mission/product-line areas critically related to the science or technology area of present interest. In addition, the team's focus should not be limited to disciplines related only to the present technology area (that tends to reinforce the status quo and commit development along very narrow lines), but should be broadened to disciplines and technologies that have the potential to impact the overall roadmap's highest-level objectives (that would be more likely to provide equitable consideration to revolutionary new paradigms or innovations).

B.4. Stakeholder-driven

A roadmap should have a clear sense of purpose and ownership for it to be successful. Thus, industry roadmaps are most successful when driven by industry, even if government, universities, and consortia are big players in the process. Likewise, product-technology roadmaps are best done by those responsible for the outcome (e.g., the product manager).

B.5. Normalization and standardization

For roadmaps that will be used as a basis for comparison of S&T programs or projects, another important factor is normalization and standardization across different roadmaps, development teams, and S&T areas. For S&T areas that have some similarity, use of common experts (on the development teams) with broad backgrounds, which overlap the disciplines, can provide some degree of standardization. For very disparate S&T areas, some allowances need to be made for the relative strategic value of each discipline to the organization, and arbitrary corrections applied for benefit estimation differences and biases.

B.6. Roadmap criteria

Criteria for roadmap component selection are also required. For retrospective roadmaps, that tend to focus on the critical S&T events that led to successful technologies/systems, the definition of criteria for: "successful" and "critical" is of utmost importance for establishing the credibility of the roadmap. In all roadmaps, it is crucial to define criteria for selecting nodes, quantifying nodes, and quantifying links.

B.7. Reliability

A factor of equal importance to criteria is reliability or repeatability. To what degree would a roadmap be replicated if a completely different development team were involved in its construction? If each development team were to construct a completely different roadmap for the same topic, then what meaning or credibility or value can be assigned to any roadmap? To minimize repeatability problems, a large segment of the competent technical community (to the degree possible within organizational constraints) should be involved in the construction and review of the roadmap.

B.8. Relevance to future actions

Another factor of equal importance to criteria is the relevance of the roadmap to future actions.

Every S&T Roadmap, and associated data, presented in a study or briefing should have a decision focus. It should contribute to the answer of a question, which in turn would be the basis of a recommendation for future action.

Roadmaps, which do not perform this function, become an end in themselves, offer no insight, and provide no contribution to decision making.

B.9. Cost

An additional critical factor is cost. The true total costs of developing a high quality roadmap with substantial community input can be considerable, but tend to be understated. For high-quality roadmaps, where sufficient expertise is represented on the development team, the major contributor to total costs is the time of all the individuals involved in developing and reviewing the roadmap. With high quality personnel involved in the development and review process, time costs are high, and the total development costs can be non-negligible.

B.10. Global data awareness

A crucial factor is global data awareness. A quality roadmap should include all global S&T projects, developed systems or operations, or events, that are in any way supportive of or related to the overall roadmap objectives. This factor is foundational to S&T investment strategy, and how a program or body of S&T is planned, selected, managed, coordinated, integrated, and transitioned. It is imperative that the latest information technology resources be used to the greatest extent possible during the complete roadmap development process to insure that global S&T resources are being exploited maximally.

B.11. Functional node relationships

Roadmaps should incorporate functional relationships among nodes, wherever possible, to allow parameter sensitivities to be examined [40]. The impact of cost, performance, schedule, and risk variations for any node (S&T program/project) on adjacent nodes and on total system performance should be straightforward to calculate using different trade-off techniques.

B.12. Flexible display

Effective utilization of these sensitivity and parametric variation studies requires that modern roadmaps display techniques using the latest in information technology. Roadmaps are intrinsically node and link attributes covering many dimensions, and any effective display technique requires the capability to traverse many dimensions rapidly and easily. Most present roadmap manifestations are in two-dimensional form, severely limiting portrayal of the complex network dynamics occurring. The Zurcher and Kostoff [39] roadmaps were two-dimensional graphical representations that used a variety of physical display techniques (colors, shadings, line breaks, etc.) to effectively increase the number of dimensions/attributes displayed. To utilize the full display power of present-day technology, computer-based hyper-linked systems are required to display the roadmap dynamics across the fundamental dimensions of cost, performance, risk, and schedule. Additionally, these systems should have the capability to incorporate additional dimensions such as node definitions, node background/history, coordination of any technology node with other technologies, representation of any technology node in the context of global efforts in related technology development, performers for each technology node, progress/products for each technology node, potential multiple applications of each technology node, funding adequacy of each node, and other attributes and narrative information.

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Selected Partially Annotated Bibliography of Disruptive Technologies

Peterson, L, Anderson, T, Culler, D, Roscoe, T, A blueprint for introducing disruptive technology into the Internet, COMPUTER COMMUNICATION REVIEW, 33:1, 59-64, Jan 2003
This paper argues that a new class of geographically distributed network services is emerging, and that the most effective way to design, evaluate, and deploy these services is by using an overlay-based testbed. Unlike conventional network testbeds, however, we advocate an approach that supports both researchers that want to develop new services, and clients that want to use them. This dual use, in turn, suggests four design principles that are not widely supported in existing testbeds: services should be able to run continuously and access a slice of the, overlay's resources, control over resources should be distributed, overlay management services should be unbundled and run in their own slices, and APIs should be designed to promote application development. We believe a testbed that supports these design principles will facilitate the emergence of a new serviceoriented network architecture. Towards this end, the paper also briefly describes PlanetLab, an overlay network being designed with these four principles in mind.

Barrett, PS, Hybrid concrete: improved processes and performance, PROCEEDINGS OF THE INSTITUTION OF CIVIL ENGINEERS-STRUCTURES AND BUILDINGS, 156:2, May 2003.
This paper presents the results of a study of three very successful Hybrid* concrete projects. Supply chain analyses are described and, in the event, the situations found are typified as networks. Problem areas are identified together with various illustrations of good practice, with a particular stress on the necessity for intensive and effective informal communications. The particular problems attendant on the design side of the process, rooted in role confusion and a lack of design fixity are highlighted. This links to the suggestion that as the knowledge of Hybrid systems becomes better understood and is more fully communicated through codification then many of these problems should evaporate. That is, Hybrid can move from being a disruptive technology and become a sustaining technology for the industry and its clients.

King, SM, Verlinden, M, Christensen, CM, Through the looking glass of disruptive technology, SOLID STATE TECHNOLOGY, 46:4, April 2003.

Bucher, P, Birkenmeier, B, Brodbeck, H, Escher, JP, Management principles for evaluating and introducing disruptive technologies: the case of nanotechnology in Switzerland, R & D MANAGEMENT, 33:2, March 2003.
In this paper we address the issue of evaluating and introducing disruptive technologies. The empirical data was compiled in an interview-based survey of 20 Swiss organizations of different sizes and from different industries. All of them have been facing the issue of evaluating nanotechnology, and most of them are currently dealing with the introduction of nanotechnology in their products and processes. The underlying framework was elaborated using approaches mainly found in the following streams of technology management literature: technology intelligence, technological decision-making, and technological capability building. The aim of our project was not to advance new management concepts, but to elaborate management principles allowing the organizations to master the challenges during evaluation and introduction of disruptive technologies. We defined these principles through identifying success factors as well as possible pitfalls, and by distilling best management practices in evaluating and introducing nanotechnology.

Curley, MG, Peer-to-peer computing enabled collaboration, COMPUTATIONAL SCIENCE-ICCS 2002, PT II, PROCEEDINGS, 2330, 2002.
This paper discusses how peer-to-peer computing is emerging as a disruptive technology for global collaborative solutions. It explains how peer-to-peer computing can enable Dew collaborative solutions while significantly decreasing IT costs and improving IT asset utilization. An overview of the technology and usage models are discussed whilst the benefits are illustrated through a short case study from Intel. Finally the value proposition for peer-to-peer computing is summarized.

Sandy, LG, Schroeder, SA, Primary care in a new era: Disillusion and dissolution?, ANNALS OF INTERNAL MEDICINE, 138:3, 4 Feb 2003.
The current dilemmas in primary care stem from 1) the unintended consequences of forces thought to promote primary care and 2) the "disruptive technologies of care" that attack the very function and concept of primary care itself. This paper suggests that these forces, in combination with "tiering" in the health insurance market, could lead to the dissolution of primary care as a single concept, to be replaced by alignment of clinicians by economic niche. Evidence already exists in the marketplace for both tiering of health insurance benefits and corresponding practice changes within primary care. In the future, primary care for the top tier will cater to the affluent as "full-service brokers" and will be delivered by a wide variety of clinicians. The middle tier will continue to grapple with tensions created by patient demand and bureaucratic systems but will remain most closely aligned to primary care as a concept. The lower tier will become increasingly concerned with community health and social justice. Each primary care specialty will adapt in a unique way to a tiered world, with general internal medicine facing the most challenges. Given this forecast for the future, those concerned about primary care should focus less on workforce issues and more on macro health care financing and organization issues (such as Medicare reform); appropriate training models; and the development of a conception of primary care that emphasizes values and ethos, not just function.

Kirchhoff, BA, Kassicieh, SK, Walsh, ST, Introduction to the special cluster on the commercialization of disruptive technologies and discontinuous innovations, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, 49:4, Nov 2002.

Myers, DR, Sumpter, CW, Walsh, ST, Kirchhoff, BA, A practitioner's view: Evolutionary stages of disruptive technologies, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, 49:4, Nov 2002.
Researchers at Sandia National Laboratories have seen that disruptive technologies when successful evolve into three distinct stages. Each stage is characterized by a distinct market size and level of infrastructure. Each stage elicits specific behavioral responses. Stage I is achieved when the proposed concept is demonstrated. At this point, the technology has not found a market and essentially none of the required infrastructure exists. In Stage 2, the emergent technology establishes a specific application for a limited market, which enables the development and maturation of a limited infrastructure. Stage 3 is achieved when the technology achieves widespread application in the solution set for product developers. Experience suggests that Stage 2 is achieved only when the disruptive technology can provide a unique solution to a problem of substantial importance. However, to expand to the commercial maturity accomplished in Stage 3, the emergent technology must either continue to find important but unresolved problems or alternatively must compete for differential advantage against the defensive innovations of established technologies in the targeted application areas. "True believers" who are committed to the emergent technology sustain Stage 1 and Stage 2 activities. Finally, the authors note the importance of targeting

the correct application area to evolve the technology from Stage 2 to Stage 3 behavior. The evolution from Stage 2 to Stage 3 can be considered a coupled system as the emergent technology encounters feedback from the marketplace and competition from established technologies. These factors introduce nonlinearities in the system, making the application of traditional linear technology forecasting techniques problematic for emergent technologies. The authors provide anecdotal evidence in the form of a case study centered on ion implantation, a disruptive technological step in a sustaining technology platform.

Walsh, ST, Kirchhoff, BA, Newbert, S, Differentiating market strategies for disruptive technologies, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, 49:4, Nov 2002.
The literature is full of anecdotes that show new small firms attacking existing markets with innovations based upon disruptive technologies and achieving phenomenal success. Because of this, some theorists argue that disruptive technologies are best commercialized by new small firms. If this is true, can a logical rationale be developed that explains this unique capacity of new firms? If so, can empirical research of new and established firms in an industry fraught with a disruptive technology identify the advantages that new firms have over established firms in the commercialization process? The purpose. of this paper is to examine the different roles of established and new firms in disruptive technology commercialization. The authors begin by developing a model of the innovation process beginning with technology creation and ending with user adoption and application. From this model they develop propositions for testing. The authors use survey data collected from 72 micro- electro-mechanical-systems (MEMS) manufacturing firms. Their results from the MEMS industry show that established firms rarely commercialize disruptive technologies and then prefer to use market-pull strategies to accomplish this. New firms select primarily disruptive technologies and choose either market-pull or technology-push strategies for commercialization. Perhaps more important; time to market for new firms is one-fourth that for established firms. These results suggest that new firms have two advantages in commercialization of disruptive technologies-flexibility in marketing strategy and much shorter times to market.

Linton, JD, Forecasting the market diffusion of disruptive and discontinuous innovation, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, 49:4, Nov 2002.
This paper builds on existing knowledge of diffusion forecasting and integrates it with the disruptive and discontinuous innovation literature. Thus, a model is developed for forecasting discontinuous and disruptive innovations. This model takes into account the multiple markets served by discontinuous and disruptive innovation. The role of learning curve effects is also considered. Guidelines, based on the existing literature, are offered for the application of this methodology to forecasting the market diffusion of discontinuous and disruptive innovation. The ability to better forecast the market diffusion of disruptive and discontinuous innovation is especially important now since the convergence of many fields and advances in other areas are creating unprecedented amounts of disruptive and discontinuous innovation.

Kassicieh, SK, Walsh, ST, Cummings, JC, McWhorter, PJ, Romig, AD, Williams, WD, Factors differentiating the commercialization of disruptive and sustaining technologies, IEEE TRANSACTIONS ON ENGINEERING MANAGEMENT, 49:4, Nov 2002.
The nature of disruptive and sustaining technologies is sufficiently different to require different activities for the commercialization of these technology categories. Few theorists

have developed conceptual schemes about the different methods of commercializing these technologies. The authors take the first steps in investigating these differences by contrasting firms that commercialize disruptive technologies with those that commercialize sustaining technologies. They reveal major differences and analyze these in terms of four major commercialization components: product realization, revenue generation, research support, and market potential. Several hypotheses regarding size of the firm, its financial risk profile, and its R&D strategy are utilized.

Winseck, D, Netscapes of power: convergence, consolidation and power in the Canadian mediascape, MEDIA CULTURE & SOCIETY, 24:6, Nov 2002.
Grounded in a study of the Canadian mediascape, this article argues that trends toward media ownership consolidation are having a fundamental impact on broadcasting and the evolution of cyberspace as a whole. I argue that current trends reflect the rise of what we can call 'Machiavellian media' - communication and information systems saddled with three tasks: building the information society; populating cyberspace with workers/ citizens/users; and projecting the 'brand image' of nation-states on a global plane. The article critiques the notion that new media, especially the internet, are disruptive technologies. Among other things, cyberspace is a class-divided space. More than this, though, networks - the basis of many 'new media' - are powerful entities and those who control them influence content providers' access to people and people's access to content. The article also analyzes three other factors that are affecting the evolution of networks and cyberspace: attempts to design 'netscapes of power', the privatization of cyberlaw, and 'walled garden' strategies. Together, these strategies seek to change the Internet into a mainly 'read-only' medium and to cybernetically integrate audiences, content and all organizational resources into a self-referentially enclosed information system governed by multimedia conglomerates' need to defend their investments in a model of media evolution that has, at best, weak cultural foundations.

Birat, JP, Innovation paradigms for the steel industry of the 21st Century. Future directions for steel industry and continuous Casting, REVUE DE METALLURGIE-CAHIERS D INFORMATIONS TECHNIQUES, 99:11, 2002.
The History of Industry mirrors the History of Society, by which it is also reflected. Its purpose is to describe the emergence of technologies which exhibit a personality of their own and not only bring out new possibilities, but also a stiffness to which all stakeholders should to some extend yield, especially the decision makers in business circles. Technologies that succeed commercially are those which are able to provide sustainable answers to the demands put forward successively by each one of them. These robust technologies, which are not identical to the disruptive technologies of K. Brimacombe, meet criteria, which in effect are true innovation paradigms. A list of these is proposed here, stemming from a retrospective analysis of process development in the steel industry. It is probably adventurous to project these into a technological forecasting exercise, due to the non-deterministic nature of history. But this is an interesting way to focus on the challenges that should be met in the future and that no stakeholder would refuse to face.

Cosier, G, Hughes, PM, The problem with disruption, BT TECHNOLOGY JOURNAL, 19:4, Oct 2001.
Back in January 1995 Clayton Christensen and Joseph Bower wrote an article, 'Disruptive Technologies: catching the wave', in the Harvard Business Review, in which they argued: 'No matter the industry, a corporation consists of business units with finite life spans: the technological and market bases of any business will eventually disappear. Good businesses

will often be adept at managing a process of incremental improvement, but this kind of incremental change, what they call 'sustaining technologies', is not the focus of this paper but rather disruptive technologies, which change the rules and leave established businesses with nowhere to go.

Hughes, PM, Cosier, G, What makes a revolution? Disruptive technology and social Change, BT TECHNOLOGY JOURNAL, 19:4, Oct 2001.
Never before? Every age tends to think it is special, facing problems that have never occurred before the 'arrogance of the present'. Disruption has occurred before, yet this generation (or the last, or the next) might well be facing unique problems. There is good evidence that special times are here or hereabouts. Globalisation is new mankind has always totally remade or devastated small areas of the planet, but now we have the capacity to affect everywhere at once. The Max Plank Institute predicts demographic trends. One such prediction says that around 2070 the human population will start to decline for reasons other than disaster or disease that will be the first time in history that material success has led to fewer people on Earth. So maybe there are some truly new effects to be considered. What might be new about disruption this time are its speed, strength of impact, and the global compass of its effect.

Hughes, PM, Cosier, G, Whose power is it anyway?, BT TECHNOLOGY JOURNAL, 19:4, Oct 2001.
Disruptive technologies disrupt not because no one sees them coming, nor because of their technical superiority, but because something in their balance of price and performance meets a social or consumer need, with the result that they displace an established way of meeting market demand. Disruption then, is as much about society as it is about technology, although the two are inextricably intertwined.

Kassicieh, SK, Kirchhoff, BA, Walsh, ST, McWhorter, PJ, The role of small firms in the transfer of disruptive technologies, TECHNOVATION, 22:11, Nov 2002.
The transfer of technologies from government-operated research laboratories to commercial firms can be a challenging process especially for small and emerging entrepreneurial firms. Since the National Laboratories have become major creators of disruptive technologies and small firms are more apt to commercialize disruptive technologies, it is important to get small firms involved in these processes. This paper covers an innovative program used by Sandia National Laboratories to transfer micro-electro-mechanical systems' technology to small firms through training, prototyping and access provided to all small and large firms alike providing the impetus to small and entrepreneurial firms to create successful innovations that can generate new industries. The effect of the model on small and large firms is also shown over the last few years.

Martin, M, Revolutionary innovation in a fiscally constrained environment, NAVAL ENGINEERS JOURNAL, 112:4, July 2000.
For many years now, U.S. defense acquisition and force structure decisions have been based on the premise that the U.S. can and will maintain a commanding technological advantage over potential adversaries. The widespread access to a wide variety of modern top of the fine technologies made possible by the globalization of technology research and industrial bases and vastly improved communications has raised concern as to the validity of this premise. This paper discusses the importance of maintaining the ability within U.S. defense and industrial infrastructures to continue to lead the way in developing and integrating breakthrough technologies to maintain the U.S.'s technological advantage and the role of naval engineers in fostering and managing innovation. It discusses some of the significant

obstacles and impacts to the processes of innovation imposed by the inertia within the U.S. S well- developed defense and industrial infrastructures and today's fiscally constrained defense environment. The need for stable properly prioritized and managed defense research and development resources independent of major platform acquisition programs in order to ensure the U.S.'s ability to adjust and adapt to strategic uncertainty is identified. Differences between modernization approaches based on incremental, evolutionary change to existing systems and "disruptive" technology, which facilitates the transition from one established path of technology evolution to another, enabling revolutionary change, are also discussed.

Ferrary, M, Managing the disruptive technologies life cycle by externalising the research: social network and corporate venturing in the Silicon Valley, INTERNATIONAL JOURNAL OF TECHNOLOGY MANAGEMENT, 25:1-2, 2003.
The capability to generate and develop disruptive technologies drives the market in the high-tech sector. Traditional strategic theory recommendsinternalisation of R&D to keep a competitive advantage. The Silicon Valley example points out that the most successful high-tech companies such as Cisco Systems, Intel and Sun externalise their research by doing corporate venturing. These companies manage their portfolio of technologies by acquiring small businesses that have developed disruptive technologies. This kind of acquisitive strategy needs specific organisational and managerial practices to embed the large company in the industrial-network structure of the Silicon Valley. Thus, managers of innovation have to get a large social capital to gather information inside business networks.

D'Aveni, R, The empire strikes back - Counterrevolutionary strategies for industry leaders, HARVARD BUSINESS REVIEW, 80:11, Nov 2002.
Industry leaders frequently worry that their companies willfall victim to some revolutionary business model or disruptive technology. But new research shows that it's strategically better for incumbents to counter a revolution than to ignore or fully embrace it. Successful incumbents rely on one or more of five approaches to restrain, modify or, if necessary, neutralize a revolutionary threat. Acompany that perceives a revolution in its earliest stages can use containment strategies. By throwing up roadblocks - raising switching costs, perhaps, or launching discrediting PR efforts - an incumbent can often limit the degree to which customers and competitors accept a nascent insurgency. And, sometimes, revolutions die there. If not, early containment buys a company some time to shape the revolution so that it complements, rather than supersedes, the incumbent's strengths. And even if shaping efforts fail, they can give an industry leader more time to work out how to absorb the threat by bringing the new competencies or technologies inside the firm in such a way that they don't destroy its existing strengths and capabilities. When revolutions have progressed too far to slow them down, incumbents must take a more aggressive tack. Neutralizing strategies meet a revolution head-on and terminate it-by, say, temporarily giving away the benefits offered by the challenger for free. Annulment strategies allow the market leader to leapfrog over or sidestep the threat. These five strategic approaches need not be used in isolation, as a detailed case study of the way Anheuser-Busch countered the craft-beer revolution dramatically demonstrates. Sensible industry leaders do not lead revolutions; they know they may not survive the attempt. Instead, they prefer to lead counter-revolutions.

Anderson, B, Gate, C, Gower, AP, France, EF, Jones, MLR, Lacohee, HV, McWilliam, A, Tracey, K, Trimby, M, Digital living - people-centred innovation and strategy, BT TECHNOLOGY JOURNAL, 20:2, Apr 2002.

This paper provides a summary of a research programme at BTexact Technologies which is aimed at helping a technology innovation company to ground its innovations, to see opportunities for the exploitation of its technologies, and to create socio-technical visions which can help to drive technological innovation itself. As a by-product, the programme has also created strategic knowledge that is of critical importance to public and private policy/decision makers alike. This research is a key part of BTexact Technologies' approach to the creation of and response to disruptive technologies. Understanding 'usage by people' is absolutely critical to figuring out what is disruptive about technologies, why this isso, and therefore how to make money out of them. Since this is critical to several of BTexact's core competencies (and to those of its customers), the value of the research reported here is self-evident both to BTexact and to its customers. Without it, they will only ever make money by accident, a strategy that shareholders do not seem to find amusing.

[Anon], Six next-gen disruptive technologies, COMMUNICATIONS NEWS, 39:8, Aug 2002.

Adner, R, When are technologies disruptive? A demand-based view of the emergence of competition, STRATEGIC MANAGEMENT JOURNAL, 23:8, Aug 2002.
By identifying the possibility that technologies with inferior performance can displace established incumbents, the notion of disruptive technologies, pioneered by Christensen (1997), has had a profound effet on the way in which scholars and managers approach technology competition. While the phenomenon of disruptive technologies has been well documented, the underlying theoretical drivers of technology disruption are less well understood. This article identifies the demand conditions that enable disruptive dynamics. By examining how consumers evaluate technology, and how this evaluation changes as performance improves, it offers new theoretical insight into the impact of the structure of the demand environment on competitive dynamics. Two new constructs-preference overlap and preference symmetry-are introduced to characterize the relationships among the preferences of different market segments. The article presents a formal model that examines how these relationships lead to the emergence of different competitive regimes. The model is analyzed using computer simulation. The theory and model results hold implications for understanding the dynamics of disruptive technologies and suggest new indicators for assessing disruptive threats.

Shoemaker, DD, Linsley, PS, Recent developments in DNA microarrays, CURRENT OPINION IN MICROBIOLOGY, 5:3, June 2002.
DNA microarrays are used to quantify tens of thousands of DNA or RNA sequences in a single assay. Upon their introduction approximately six years ago, DNA microarrays were viewed as a disruptive technology that would fundamentally alter the scientific landscape. Supporting this view, the number of applications of DNA microarray technology has since expanded exponentially. Here, we review recent advances in microarray technology and selected new applications of the technology.

Drejer, A, Towards a model for contingency of Management of Technology, TECHNOVATION, 22:6, Jun 2002.
The foundation of this paper is a discussion of how different traditions and approaches to Management of Technology (MoT) at the company level can be divided into schools of thought based on a rich view of the environmental challenges facing companies today. Obviously, contingency factors should be related to empirical challenges of firms, thereby enabling technology managers to apply MoT theory pragmatically. It is argued that the existing mappings of MoT theory are. indeed, not sufficiently related to empirical

contingency factors. Thus, the main purpose of the paper is to discuss such empirical contingency factors that could be applied to MoT theory and make it more useful for technology managers in practice. The well-known distinction between technology exploitation and disruptive technological change is discussed and dismissed as too simplistic. Instead. three situations for technology management are formulated and briefly related to the MoT theory to round up the paper. The latter forms the main contribution of the paper.

Gilbert, C, Bower, JL, Disruptive change - When trying harder is part of the problem, HARVARD BUSINESS REVIEW, 80:5, May 2002.
When a company faces a major disruption in its markets, managers' perceptions of the disruption influence how they respond to it. If, for instance, they view the disruption as a threat to their core business, managers tend to overreact, committing too many resources too quickly. But if they see it as an opportunity, they're likely to corm-nit insufficient resources to its development. Clark Gilbert and Joseph Bower explain why thinking in such stark terms - threat or opportunity- is dangerous. It's possible, they argue, to arrive at an organizational framing that makes good use of the adrenaline a threat creates as well as of the creativity an opportunity affords. The authors claim that the most successful companies frame the challenge differently at different times: When resources are being allocated, managers see the disruptive innovation as a threat. But when the hard strategic work of discovering and responding to new markets begins, the disruptive innovation is treated as an opportunity. The ability to reframe the disruptive technology as circumstances evolve is not an easy skill to master, the authors admit. in facts it might not be possible without adjusting the organizational structure and the processes governing new business funding. Successful companies, the authors have determined, tend to do certain things: They establish a new venture separate from the core business; they fund the venture in stages as Markets emerge; they don't rely on employees from the core organization to staff the new business; and they appoint an active integrator to manage the tensions between the two organizations, to name a few. This article will help executives frame innovations in more balanced ways-allowing them to recognize threats but also to seize opportunities.

Christensen, CM, The opportunity and threat of disruptive technologies, MRS BULLETIN, 27:4, Apr 2002.

Van Horn, R, Disruptive technology, PHI DELTA KAPPAN, 83:7, Mar 2002.

Saleri, NG, "Learning" reservoirs: Adapting to disruptive technologies, JOURNAL OF PETROLEUM TECHNOLOGY, 54:3, Mar 2002.

Wagner, HN, The Internet: the road to more effective PET, QUARTERLY JOURNAL OF NUCLEAR MEDICINE, 45:3, Sep 2001.
We may live in the Information Age, but so far information technology (IT) has had little impact on how most nuclear medicine physicians and radiologists practice medicine. Many remain skeptical that IT can improve the care of patients, increase productivity, or enhance income. They fail to recognize that IT is a disruptive technology that will leave behind those who do not embrace it. Although hospital physicians often examine radiographic images and to a lesser degree pathology slides along with the responsible radiologist or pathologist, this collaboration occurs less often than it should in office practice. Teams of radiologists, nuclear medicine physicians, and referring physicians can use the Internet for the high-quality transfer and display of images for simultaneous consultation. People can now be connected electronically in ways never before possible, and in the next generation at speeds

that will become a thousand times faster. Nuclear medicine can take advantage of its unique position as an early adopter of digital technology to lead the way as the practice of medicine is changed forever.

Talbot, D, DARPA's disruptive technologies, TECHNOLOGY REVIEW, 104:8, Oct 2001.

Altman, ER, Ebcioglu, K, Gschwind, M, Sathaye, S, Advances and future challenges in binary translation and optimization, PROCEEDINGS OF THE IEEE, 89:11, Nov 2001.
Binary translation and optimization have achieved a high profile in recent years with projects such as the IBM DAISY open-source project, Transmeta Crusoe, HP Dynamo, Java JIT compilers such as LaTTe, and many others. Binary, translation has several potential attractions: Architecture can become a layer of software, which allows the implementation of complex legacy architecture(s) through simple hardware and the introduction of novel new architecture and microarchitecture concepts without forcing any soft-ware changes. Secondly, binary translation enables significant software optimizations of the kind that would push the complexity boundaries if done with hardware alone. While still in its early stages, could binary translation offer a new way to design processors, i.e., is it a disruptive technology, the term popularized by Prof. Clayton Christensen? This paper discusses this interesting question, examines some exciting future possibilities for binary translation, and then gives an overview of selected projects (DAISY Crusoe, Dynamo, and LaTTe). One future possibility for binary translation is the Virtual IT Shop. Companies such as Loudcloud currently provide computational resources as sen,ices over the Web, These seri,ices are typically implemented through large and secure server farms. If a variety of customers are to be supported, a variety of architectures (x86, PowerPC, Sparc, etc.) must be present in the fat-in. of necessity, the number of machines from each architecture is statically determined at present, thus limiting utilization and increasing cost. Binary translation offers a possible solution for better utilization: architecture as a layer of software, and hence dynamic configuration of the number of machines from each architecture in such farms. Vie Internet is radically changing the soft-ti,are landscape, and is fostering platform independence and interoperability, with paradigms such as XML, SOAP, and Java. Along the lines of software convergence, recent advances in binary JIT optimizations also present the future possibility of a convergence virtual machine (CVM). CVM is similar to the Jam Virtual Machine (JVM) in that both seek to facilitate a write-once, run-anywhere model of software development. However, the JVM suffers front the drawback that existing C/C++ applications and existing operating Systems do not run on it. CVM aims to address the remaining research challenges in allowing the same standard OS and application object code to run on different hardware platforms, through state-of-the-art JIT compilation and virtual device emulation.

Ennis, LA, TI Peer-to-peer: Harnessing the benefits of a disruptive technology., JOURNAL OF THE AMERICAN SOCIETY FOR INFORMATION SCIENCE AND TECHNOLOGY, 52:13, Nov 2001.

Brody, AB, Gottsman, EJ, Pocket Bargain Finder: A handheld device for augmented commerce, HANDHELD AND UBIQUITOUS COMPUTING, PROCEEDINGS, 1707, 1999.
The Internet has engendered a new type of commerce, commonly referred to as electronic commerce, or eCommerce. But despite the phenomenal growth of eCommerce, the vast majority of transactions still take place within the realm of traditional, physical commerce. Pocket BargainFinder is a handheld device that seeks to bridge the gap between electronic

and traditional commerce. It represents one of the earliest examples of a new breed of commerce we call augmented commerce. With Pocket BargainFinder, a consumer can shop in a physical retail store, find an item of interest, scan in its barcode, and search for a lower price among a set of online retailers. The device allows customers to physically inspect products while simultaneously comparison shopping online (where prices are often lower.) As such, Pocket BargainFinder is an example of a disruptive technology that may well transform the nature of both electronic and physical commerce. With consumers able to find the best price regardless of where they shop, the physical retailer is left at a distinct disadvantage.

Bullock, G, The new economy and disruptive technologies - Impacts on the sugar industry, INTERNATIONAL SUGAR JOURNAL, 103:1233, Sep 2001.
The pace of technological advances in the knowledge-intensive sectors such as computing, telecommunications and pharmaceuticals have brought about significant transformations in the development of new products and services. In the relatively less knowledge-intensive agro-processing sector such as sugar, advances have been incremental rather than disruptive. However, recent developments in the sugar sector suggests otherwise. This paper highlights these.

Loutfy, R, Belkhir, L, Managing innovation at Xerox, RESEARCH-TECHNOLOGY MANAGEMENT, 44:4, July-Aug 2001.
The careful and painstaking corporate planning cycle used in the typical established corporation is inherently biased toward incremental improvements in the company's existing businesses. Furthermore, it tends to be unfavourable to the nurturing and development of disruptive technologies and radical business concepts, which in turn sets a serve limitation on the growth prospects of these large companies and their ability to compete against aggressive newcomers. Xerox has attempted to pull itself out of this predicament by the creation of new corporate innovation processes, including most recently the Xerox Technology Enterprise.

Prusak, L, Cohen, D, How to invest in social capital, HARVARD BUSINESS REVIEW, 79:6, Jun 2001.
Business runs better when people within a company have close ties and trust one another. But the relationships that make organizations work effectively are under assault for several reasons. Building such "social capital" is difficult in volatile times. Disruptive technologies spawn new markets daily, and organizations respond with constantly changing structures. The problem is worsened by the virtuality of many of today's workplaces, with employees working off-site or on their own. What's more, few managers know how to invest in such social capital. The authors describe how managers can help their organizations thrive by making effective investments in social capital. For instance, companies that value social capital demonstrate a commitment to retention as a way of limiting workplace volatility. The authors cite SAS's extensive efforts to signal to employees that it sees them as human beings, not just workers. Managers can build trust by showing trust themselves, as well as by rewarding trust and sending clear signals to employees. They can foster cooperation by giving employees a common sense of purpose through good strategic communication and inspirational leadership. Johnson & Johnson's well-known credo, which says the company's first responsibility is to the people who use its products, has helped the company in times of adversity, as in 1982 when cyanide in Tylenol capsules killed seven people. Other methods of fostering cooperation include rewarding the behavior with cash and establishing rules that get people into the habit of cooperating. Social capital, once a given in organizations, is

now rare and endangered. By investing in it, companies will be better positioned to seize the opportunities in today's volatile, virtual business environment.

LoPiccolo, P, Disruptive technologies, COMPUTER GRAPHICS WORLD, 24:5, May 2001.

Christensen, C, Craig, T, Hart, S, The great disruption, FOREIGN AFFAIRS, 60:2, Mar-Apr 2001.
A key reason national economies rise and fall these days is their ability to nurture "disruptive technologies"-innovations that lead to new classes of products that are cheaper, better, and more convenient than their predecessors. America's ability to exploit disruption has led to its recent boom, while Japan's failure to do so has led to stagnation. Other countries should heed the lesson.

Tovstiga, G, Fantner, EJ, Implications of the dynamics of the new networked economy for e-business start-ups: the case of Philips' Access Point, INTERNET RESEARCH-ELECTRONIC NETWORKING APPLICATIONS AND POLICY, 10:5, 2000.
Explores how the spread of connectivity and the introduction of new standardsis driving the emergence of entirely new value constructs that deliver to multiple stakeholders. Examines the new economics of network growth and the associated "economics of increasing returns". Looks at the dynamic trajectory of this function from the perspective of new business development at the various stages of the trajectory and derives management implications for each stage in terms of appropriate competitive and market strategies, organizational structure and management practices. Applies the resulting framework to discuss specific implications for the business start-up of Access Point, Philips' new multimedia, voice technology-based information and on-line services venture that has at its core a disruptive technology.

Nault, BR, Vandenbosch, MB, Research report: Disruptive technologies - Explaining entry in next generation information technology markets, INFORMATION SYSTEMS RESEARCH, 11:3, Sep 2000.
The most difficult challenge facing a market leader is maintaining its leading position. This is especially true in information technology and telecommunications industries, where multiple product generations and rapid technological evolution continually test the ability of the incumbent to stay ahead of potential entrants. In these industries, an incumbent often protects its position by launching prematurely to retain its leadership. Entry, however, happens relatively frequently. We identify conditions under which an entrant will launch a next generation product thereby preventing the incumbent from employing a protection strategy. We define a capabilities advantage as the ability to develop and launch a next generation product at a lower cost than a competitor, and a product with a greater market response is one with greater profit flows. Using these definitions, we find that an incumbent with a capabilities advantage in one next generation product can be overtaken by an entrant with a capabilities advantage in another next generation product only if the entrant's capabilities advantage is in a disruptive technology that yields a product with a greater market response. This can occur even though both next generation products are available to both firms. We also show that the competition may require the launching firm to lose money at the margin on the next generation product.

Xu, JM, Plastic electronics and future trends in microelectronics, SYNTHETIC METALS, 115:1-3, Nov 2000.
The celebrated information technology (IT), has been a phenomenal success. But, it is a narrow one. It has marched along a one-dimensional path of information processing and

transmission, but extended little to the left - acquiring information, or to the right executing on information. It is in the tremendous space and potential to the left and right of the evolution path that plastic electronics is envisioned as an enabling technology. Complementing the ever more powerful microelectronics, it has the potential to be a disruptive technology to microelectronics. While this has always been a distant possibility in the past, the time for a major breakthrough is now within sight. This has much to do with the state of microelectronics and with the recent profound progress in developing organic electronic materials. Microelectronics, as the engine driving today's IT advances, has come to a crossroads. On the road to nanoelectronics, one sees exponentially increasing cost and diminishing return with billion dollar IC fab cost doubling every generation. The high cost is, on the one hand, squeezing out all but the largest players and on the other, slowing down innovation from within. Troubles at the physical foundation of today's microelectronics are of as much concern, if not more so. The wiring challenge and the power dissipation crisis are only going to get worse with each further step of miniaturization. These problems are deeply rooted in the much-hyped digitalization, i.e. the paradigm of binary and serial signal processing. In this state of microelectronics, the opportunities for alternative technologies are emerging, and will be best pursued if not by our own initiatives then maybe by the movement of investors' dollars to areas of greater return. At the crossroads, microelectronics can go down to nanoelectronics. But, it can also move up to macroelectronics, and can extend to the left and to the right, where plastic electronics enters as an enabling base technology. In contrast to silicon microelectronics, plastic electronics can be large-area (macrosize IC, display, memory films), large critical feature size (macro linewidth), and compatible with a continuous rotary fabrication (printing) process rather than the batch (lithographic) fabrication. The performance of individual plastic electronic devices or ICs is unlikely to march the silicon counterparts - now or ever - one might say. But disruptive technologies do not have to satisfy the same performance criteria as existing ones because they address new products and new markets, as the Harvard Business School teaching goes.

Slywotzky, AJ, Christensen, CM, Tedlow, RS, Carr, NG, The future of commerce, HARVARD BUSINESS REVIEW, 78:1, Jan-Feb 2000.
As we enter the twenty-first century, the business world is consumed by questions about e-commerce. In this;article, four close observers of e-commerce speculate about the future of commerce. Adrian Slywotzky believes the Internet will overturn the inefficient push model of supplier-customer interaction. He predicts that in all sorts of markets, customers will use choiceboards-interactive, on-line systems that let people design their own products by choosing from a menu of attributes, prices, and delivery options. And he explores how the shifting role of the customer-from passive recipient to active designer-will change the way companies compete. Clayton Christensen and Richard Tedlow agree that e-commerce, on a broad level, will change the basis of competitive advantage in retailing. The essential mission of retailers - getting the right product in the right place at the right price at the right time - is a constant. But over the years retailers have fulfilled that mission differently thanks to a series of disruptive technologies. The authors identify patterns in the way that previous retailing transformations have unfolded to shed light on how retailing may evolve in the Internet era. Nicholas Carr takes issue with the widespread notion that the Internet will usher in an era of "disintermediation," in which producers of goods and services bypass wholesalers and retailers to connect directly with their customers. Business is undergoing precisely the opposite phenomenon-what he calls hypermediation. Transactions over the Web routinely involve all sorts of intermediaries. It is these middlemen that are positioned to capture most of the profits.

Anderson, KR, From paper to electron: How an STM journal can survive the disruptive technology of the Internet, JOURNAL OF THE AMERICAN MEDICAL INFORMATICS ASSOCIATION, 7:3, May-Jun 2000.
The Internet represents a different type of technology for publishers of scientific, technical, and medical journals. It is not a technology that sustains current markets and creates new efficiencies out is, rather, a disruptive technology that could radically alter market forces, profit expectations, and business models. This paper is a translation and amplification of the research done in this area, applied to a large- circulation new science journal, Pediatrics. The findings suggest that the journal of the future will be electronic, have a less volatile cost structure, be supported more by services than by content, be less able to rely on subscription revenues, and abandon certain elements of current value networks. It also provides a possible framework for other publishers to use to evaluate their own journals relative to this disruptive technology.

[Anon], Should you fear disruptive technology?, FORTUNE, 141:7, April 2000.

Clarke, P, Privat, J, Patus, ES, Tsirtsis, G, FreeUnet - disruptive technology IP network research platform, BT TECHNOLOGY JOURNAL, 18:1, Jan 2000.
FreeUnet is a research platform for future IP (internetworking protocol) protocols and applications. Development and experimental software has to coexist with the demands of real users and their daily office automation and intranet/Internet access. This paper describes its current state and the work for which it is used.

Swanekamp, R, Distributed generation seeks market niches, POWER, 143:6, Nov-Dec 1999.
Proponents say distributed generation is a "disruptive" technology that will force large central plants and high- voltage transmission lines to go the way of the slide rule. Sure, there's room for innovation. But when you get past the hype, you find some excellent niche opportunities that-in the foreseeable future anyway will be filled largely by old standby technologies.

Abramovitch, DY, Fuzzy control as a disruptive technology, IEEE CONTROL SYSTEMS MAGAZINE, 19:3, Jun 1999.

Williams, RS, Computing in the 21st century: nanocircuitry, defect tolerance and quantum logic, PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON
SERIES A-MATHEMATICAL PHYSICAL AND ENGINEERING SCIENCES, 356:1743, Aug 1998.
The geometrical scaling era of microelectronics technology will end around the year 2010, if current extrapolations of physical and economic issues are valid. Computers built then should be 256 times as capable as the current generation, according to industry projections. However, physical laws suggest that it should be possible to compute non-reversibly at least 10(9) times present speeds with the expenditure of only 1W of electrical power. The challenges faced by those who intend to build affordable appliances with capabilities far beyond those of microelectronic circuits are to invent new computer architectures suitable for nanometre-scale devices and techniques to fabricate and assemble vast numbers of such devices inexpensively. These circuits will operate according to quantum mechanical principles: and will necessarily be very different from those based on present technology.

Mensour, NA, Margaritis, A, Briens, CL, Pilkington, H, Russell, I, Developments in the brewing industry using immobilised yeast cell bioreactor systems, JOURNAL OF THE INSTITUTE OF BREWING, 103:6, Nov-Dec 1997.
The use of immobilised yeast cell systems in industry has been extensively reported in the literature. The brewing industry is closely examining immobilisation technology and evaluating its merits. Various immobilisation methods are available to researchers and the nature of the application often dictates the choice of an immobilisation matrix. Industrial scale systems utilising immobilised yeast cells adsorbed to pre- formed carriers have been used for the production of low alcohol beers and for maturation or secondary fermentation of beer. Research relating to the primary fermentation of beer continues and several groups have developed laboratory scale systems. An overview of the respective technologies is provided and several relevant industrial applications cited.

Bower, Jl, Christensen, Cm, Disruptive Technologies – Reply, HARVARD BUSINESS REVIEW, 73:3, May-Jun 1995.

Marks, G, Disruptive Technologies, HARVARD BUSINESS REVIEW, 73:2, Mar-Apr 1995.

Saldich, Rj, Disruptive Technologies – Reply, HARVARD BUSINESS REVIEW, 73:2, Mar-Apr 1995.

Shapiro, Bp, Disruptive Technologies – Reply, HARVARD BUSINESS REVIEW, 73:2, Mar-Apr 1995.

Carruthers, Jr, Disruptive Technologies – Reply, HARVARD BUSINESS REVIEW, 73:2, Mar-Apr 1995.

Bower, Jl, Christensen, Cm, Disruptive Technologies - Catching The Wave, HARVARD BUSINESS REVIEW, 73:1, Jan-Feb 1995.
One of the most consistent patterns in business is the failure of leading companies to stay at the top of their industries when technologies or markets change. Why is it that established companies invest aggressively - and successfully - in the technologies necessary to retain their current customers but then fail to make the technological investments that customers of the future will demand? The fundamental reason is that leading companies succumb to one of the most popular, and valuable, management dogmas: they stay close to their customers. Customers wield extraordinary power in directing a company's investments. But what happens when a new technology emerges that customers reject because it doesn't address their needs as effectively as a company's current approach? In an ongoing study of technological change, the authors found that most established companies are consistently ahead of their industries in developing and commercializing new technologies as long as those technologies address the next-generation- performance needs of their customers. However, an industry's leaders are rarely in the forefront of commercializing new technologies that don't initially meet the functional demands of mainstream customers and appeal only to small or emerging markets. To remain at the top of their industries, managers must first be able to spot the technologies that fall into this category. To pursue these technologies , managers must protect them from the processes and incentives that are geared to serving mainstream customers. And the only way to do that is to create organizations that are completely independent of the mainstream business.

Adapting Future Wireless Technologies. - Final rept.-Army Science Board-2001 Ad Hoc Study. ***Army Science Board, Washington, DC.,*** **Technical report NTIS Order Number: ADA412643**
The Army Science Board Panel focused on: (1) Identifying and assessing wireless technologies that may enhance and support the features required to ensure tactical information dominance; (2) Addressing the role of information management in sizing system capacity and issues such as quality of service; (3) Evaluating the degree of enhancement that could be offered by commercial technologies in each of the layers in the 3-D architecture (terrestrial, A/B, space) to achieve connectivity; (4) Addressing vulnerabilities and methods to counter use by adversaries. (5) Addressing issues posed by legacy systems. (6) Addressing joint and coalition issues. The Panel's overarching recommendations include investing more in wireless infrastructure based on commercial advances, focusing management attention on communications UAVs and payloads, developing systems capable of multiple air interfaces with access to multiple bands, establishing an Army process for systematically evaluating new, disruptive technologies & integrating them into the GIG, and treating Army wireless systems in a merged context of 'Network Operations' comprising converged voice and data. The Panel also recommends that JTRS should be directed toward incorporating future commercial waveforms, and that the spectrum management business model should be reengineered to support flexible, shared access to spectrum.

Design Methodology Development and Education for Naval System Affordability. - Annual rept. 15 Oct 2001-14 Oct 2002. ***Georgia Inst. of Tech., Atlanta. School of Aerospace Engineering.*** **Oct 2002, D. N. Mavris , Technical report NTIS Order Number: ADA406812**
There is a growing need in the Navy for the ability to discern between whether to invest in evolutionary or 'disruptive' solutions. The ultimate motivation of this research task is to understand the nature of technology transition dynamics, from an engineering and S&T investment point of view in order to maximize the probability of success of S&T investments. The approach is study rise/run analysis and techniques for linking business strategy and technology dynamics.

Technology Paradigm Shifts Commercial Survival Lessons. ***Brown (D.H.) Associates, Inc., Port Chester, NY.,*** **Technical report NTIS Order Number: ADA394667, May 2001, D. Brown.**

Model for Technology Assessment and Commercialization for Innovative Disruptive Technologies. ***Sandia National Labs., Albuquerque, NM.; Department of Energy, Washington, DC.*** **Conference proceedings NTIS Order Number: DE2001-766612 , Aug 2000, J. Hruby, S. K. Kassicieh, S. T.**
To commercialize disruptive technologies, new technology commercialization models need to be used. These models include expeditionary marketing but also should focus on the type of competencies that the R&D organizations possesses to be able to attract new partners in the process. This paper looks at these models and applies them to the LIGA processes at Sandia National Laboratories/Livermore.

Knowledge Warrior for the 21st Century. Catalysts for Cultural Change. - Strategy research rept. ***Army War Coll., Carlisle Barracks, PA.,*** **Technical report NTIS Order Number: ADA380132 , May 2000, S. Johns, M. Shalak, M. Luoma, D. Fore**
The Knowledge Warrior (KW) concept is based upon sound Knowledge Management (KM) practices. Our proposed KW would bridge the gap that currently exists between information providers and military decision-makers. We believe KWs will become an ever-

growing aspect of military operations and that KM will ultimately become the key skill of its practitioners. Our concept of KW sees the quest for knowledge as a continuous process whereby information is analyzed, synthesized and applied as a force multiplier. It transcends the boundaries of intelligence, operations, strategy, and communications. The KW will afford his commander a unique lens through which to view battlefield conditions and situations, as well as probe the future. People are the linchpins of the KW program. We recommend that the services undertake efforts to recruit individuals with the aptitude and talent required to function in the KW capacity. Our KW concept represents a disruptive technology in many respects. However, we believe that this knowledge-based discipline will serve as a catalyst for our armed forces' transformation in the new millennium.

Transfer of Disruptive Technologies: Lessons Learned from Sandia National Laboratories.
Sandia National Laboratories (SNL), Albuquerque, NM, and Livermore, CA (United States).; Department of Energy, Washington, DC. **Technical report NTIS Order Number: DE00756077 , Apr 2000, J. D. McBrayer**
Sandia National Laboratories has learned through their process of technology transfer that not all high tech transfers are alike. They are not alike by the nature of the customers involved, the process of becoming involved with these customers and finally and most importantly the very nature of the technology itself. Here they focus on technology transfer in the microsystems arena and specifically the sacrificial surface version of microsystems. They have learned and helped others learn that many MEMS applications are best realized through the use of surface micromachining (SMM). This is because SMM builds on the substantial integrated circuit industry. In this paper they review Sandia's process for transferring a disruptive MEMS technology in numerous cases.